Pavement Management

The New York State Thickness Design Manual For New and Reconstructed Pavements

TECHNICAL SERVICES DIVISION
NEW YORK STATE DEPARTMENT OF TRANSPORTATION
Mario M. Cuomo, Governor/John C. Egan, Commissioner

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I. INTRODUCTION

A. Background

The purpose of this manual is to provide information on the background, rationale, and details behind New York State Department of Transportation (NYSDOT) policy for thickness design of new and reconstructed pavements. This information is presented in accordance with Federal Highway Administration (FHWA) Policy FAPG 23-1-G-626, requiring each state highway agency to install a pavement management system acceptable to FHWA by January 1993. It has been determined by the NYSDOT pavement design task force that positive pavement drainage and increased pavement life are important aspects in designing quality pavements. This manual is based on the American Association of State Highway and Transportation Officials (AASHTO) 1986 *Guide for the Design of Pavement Structures* (1) for determining pavement thickness, as well as using a treated open-graded permeable base layer with continuous edge drains in the pavement structure to provide for positive drainage. This approach is consistent with the Brookings Institution *Roadwork* report, AASHTO European pavement tour results, Strategic Highway Research Program (SHRP) initiatives, and FHWA pavement design and drainage guides. (2)

This manual uses the aforementioned recommendations, current national and international technology, and current performance experience to set standards for long-lasting pavements. The AASHTO pavement thickness design equation parameters included in this manual are based on findings of Engineering Research and Development Bureau Research Project 202-1 (3). Adjustments have been applied to the AASHTO rigid-pavement-thickness design equation to reflect actual pavement performance in New York State. Also, the Engineering Research and Development Bureau has conducted independent pavement thickness determinations (4) based on mechanistic-empirical fatigue analyses; these investigations confirm the pavement thickness recommendations presented here. It is believed that these new pavement design techniques, when implemented, will produce higher-quality, longer-lasting pavement structures with improved long-term performance. This new design philosophy should also minimize future maintenance and traffic disruptions, and provide long-term economic benefits, particularly for high-volume roads.

The AASHTO *Design Guide* provides a reasonable methodology in designing for adequate structural capacity of the pavement structure. However, it neglects to account for lack of uniform support in the subgrade due to non-uniform frost-susceptible soils, or to provide adequate support for construction equipment due to unstable subgrade soils. Numerous subgrade improvement methods have been used by NYSDOT in the past to account for these situations, as outlined in Appendix B.

The NYSDOT pavement design task force recommends that all new and reconstructed pavements in New York State be designed for a 50-year life. Note that this longer 50-year design life is predicated on structural integrity of the pavement structure as a whole. A flexible pavement obviously will require some kind of

rehabilitation (probably periodic thin overlays or recycling of the existing asphalt due to the aging process) during this 50-year period. This should be incorporated into any life-cycle-cost analyses. It is believed that rigid pavements will require preventive maintenance and minor rehabilitation (such as joint resealing and surface grinding to restore friction) during the 50-year design life.

Traffic data input parameters to determine 80-kN (18-kip) Equivalent Single Axle Loads (ESALs) should be obtained from your regional office for each specific project.

Pavement type selection is not dealt with in this manual. NYSDOT's methodology for pavement type selection is covered in Engineering Instruction 92-015 issued by the Design Quality Assurance Bureau, titled "Project-Level Pavement Selection Process."

B. Objectives

This design manual has six objectives:

1. To provide pavement-thickness design tables based on the AASHTO design equation for flexible pavements, and a revised design equation for rigid pavements based on NYSDOT experience, to expedite the thickness design process.

2. To familiarize designers with the parameters used as input to the AASHTO design equations in determining these pavement thicknesses. These are modified according to NYSDOT's past pavement performance experience.

3. To familiarize designers with procedures used to determine rigid pavement slab length, dowel size, and longitudinal tie bar size and spacing as shown in the design tables.

4. To explain the concept of the 80-kN (18-kip) Equivalent Single Axle Load (ESAL) and provide designers with methods and procedures to predict future ESALs (Appendix A).

5. To briefly explain the new shoulder design policy: full-depth tied portland cement concrete shoulders for rigid pavements, and full-depth asphalt concrete shoulders for flexible pavements.

6. To briefly explain the new pavement drainage policy: a 100-mm (4-in.) layer of either cement- or asphalt-treated permeable base beneath rigid pavements, and a 100-mm (4-in.) layer of asphalt-treated permeable base beneath flexible pavements, both with continuous edge drains and outlets.

C. Procedures

This manual deals with NYSDOT procedures for design of new and reconstructed pavement structures. This includes thickness design of rigid and flexible pavements and/or design of all other individual components contained in the pavement structure. Guidelines for determination of rigid slab length, dowel size and spacing, and tied-rigid-shoulder reinforcement size and spacing are also included. Wherever possible, this manual uses hard metric conversions to the extent practical.

The basis for the procedure NYSDOT is adopting for design of new and reconstructed pavement structures rests in the 1986 AASHTO *Design Guide*. Some parameters used in the AASHTO design equations for pavement thickness determination are modified according to materials testing and experience that NYSDOT has accumulated through the years, along with recent studies aimed at substantiating recommendations contained in this manual. Pavement drainage is provided here by incorporating a treated permeable base layer, along with continuous 100-mm (4-in.) diam perforated plastic edge drains with non-slotted outlets every 76 m (250 ft). This drainage system is based on numerous discussions with other state agencies and European countries and on their experiences. NYSDOT is also implementing a new shoulder design policy. Rigid pavements will be designed with full-depth tied rigid shoulders, with the longitudinal joint along the right lane located 0.6 m (2 ft) to the right of the lane edge (pavement marking) to reduce stress at the pavement shoulder joints and provide a stable section to maintain traffic during future maintenance and rehabilitation operations. Flexible pavements will be designed with full-depth flexible shoulders, providing a uniform section across the entire pavement, as well as a stable section to maintain traffic during future maintenance and rehabilitation operations. Typical cross-sections preceding the design tables in this manual (Figs. 1 and 2) illustrate this new design policy. Major component changes compared to previous designs to account for increased pavement life are as follows:

1. Potentially thicker rigid-pavement slabs [up to 325-mm (13-in.) thick],

2. Potentially thicker flexible-pavement subbase course(s) [up to 900-mm (36-in.) thick],

3. Full-depth rigid (tied) and flexible shoulders, and

4. Pavement drainage via a 100-mm (4-in.) thick treated permeable base with continuous edge drains outletting approximately every 76 m (250 ft).

Thickness of rigid and flexible pavements can be determined from the design tables in Chapter II, which represent the new NYSDOT pavement design policy. Any requested variations in design from these tables should be directed to the Regional Soils Engineer. The Soil Mechanics Bureau is available for consultation through the Regional Soils Engineer concerning requested variations in design. Other sections of this manual provide documentation for the thickness design tables.

C. Procedures

This manual deals with NYSDOT procedures for design of new and reconstructed pavement structures. This includes the basic design of rigid and flexible pavements and/or design of all other individual components of the pavement structure. Guidelines for determination of rigid slab length, dowel size and spacing, and joint tie bar size and spacing are also included. Wherever possible, this manual uses hard metric conversions to the extent practical.

The basis for the procedure NYSDOT is adopting for design of new and reconstructed pavement structures is the 1958 AASHO Road Test. Some parameters used in the AASHTO design equations for pavement thickness determination were modified according to materials testing and experience that NYSDOT has accumulated through the years, along with recent studies aimed at substantiating recommendations contained in this manual. Pavement drainage is provided here by incorporating a treated permeable base layer, along with continuous 100-mm (4-in.) diam perforated plastic edge drains with non-slotted outlets every 76 m (250 ft). This drainage system is based on numerous discussions with other state agencies and European countries and on their experiences. NYSDOT is also implementing a new shoulder design policy. Rigid pavements will be designed with full-depth rigid shoulders, with the outside (right) lane widened 0.6 m (2 ft) to the right of the lane-edge pavement marking to reduce distress at the pavement shoulder joint, and to provide a wider area to maintain traffic during future maintenance and rehabilitation operations. Flexible pavements will be designed with full-depth flexible shoulders, providing a uniform section across the entire pavement, as well as a wider area for maintaining traffic during future maintenance and rehabilitation operations. Typical cross sections (reflecting the design tables of this manual) illustrate this new design policy. Major pavement changes compared to previous designs to account for increased pavement life are as follows:

1. Potentially thicker rigid pavement slabs (up to 325 mm (13 in.)),

2. Potentially thicker flexible-pavement subbase courses (up to 900-mm (36 in.)),

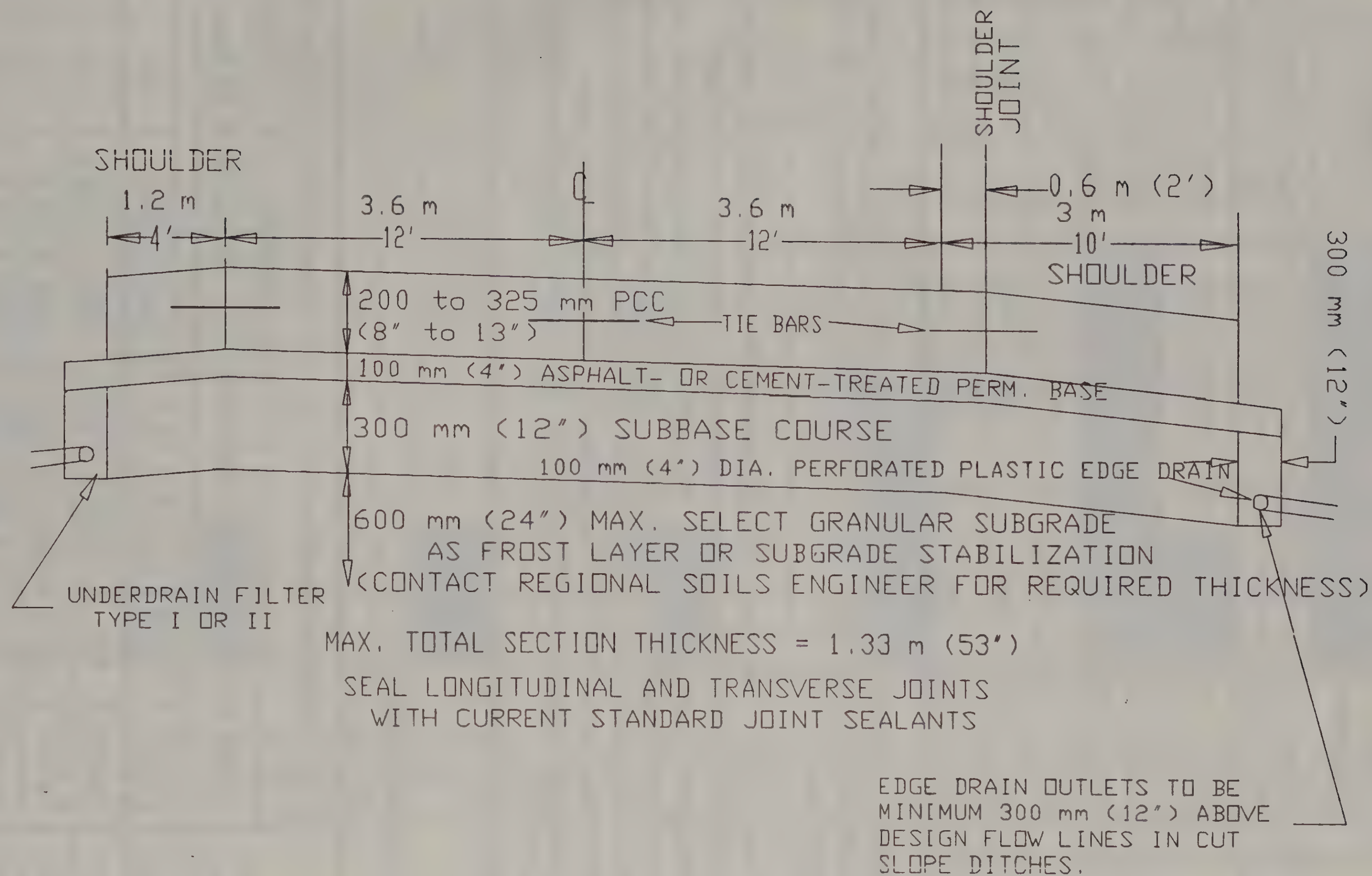
3. Full-depth rigid (tied) and flexible shoulders, and

4. Pavement drainage via a 100-mm (4-in.) treated permeable base with a continuous edge-drain system connecting approximately every 76 m (250 ft).

Thickness of rigid and flexible pavements can be determined from the design tables in Chapter III, which represent the new NYSDOT pavement design policy. Any requested variances to design from these tables should be submitted to the Regional Soils Engineer; the Soil Mechanics Bureau is available for consultation through the Regional Soils Engineer concerning requested variances in design. Other sections of this manual provide documentation for the thickness design tables.

II. TYPICAL SECTIONS AND DESIGN TABLES

Figure 1. Typical rigid pavement cross-section.



Please contact Main Office Soil Mechanics Bureau through the Regional Soils Engineer for desired typical sections deviating in the vertical from what is shown above.

Table 1. Rigid pavement design.

80-kN (18-kip) ESALs over Design Life	PCC Slab Thickness[a]		Treated Permeable Base Thickness		Minimum Subbase Course Thickness[b]		Slab Length		Dowel Bar Diameter[c]	
millions	mm	in.	mm	in.	mm	in.	m	ft	mm	in.
< 35	200	8	100	4	300	12	5.0	16	32	1¼
35 - 65	225	9	100	4	300	12	5.0	16	32	1¼
> 65 - 125	250	10	100	4	300	12	5.0	16	32	1¼
> 125 - 220	275	11	100	4	300	12	5.5	18	35	1⅜
> 220 - 380	300	12	100	4	300	12	5.5	18	38	1½
> 380 - 500[d]	325	13	100	4	300	12	5.5	18	41	1⅝

Notes: Refer to existing NYSDOT standard sheets for joint sealant design. A minimum slab thickness of 250 mm (10 in.) will be used for all interstate highways.

[a]Add 25 mm ± (1 in.) to pavement thickness with applicable slab length and dowel bar diameter where there are curbed sections with no concrete shoulders.
[b]Additional select granular subgrade may be required in accordance with subgrade improvement techniques in Appendix B. The Regional Soils Engineer should be contacted for conditions where it would be difficult to provide the required subbase course thickness, particularly for reconstruction projects in urban areas.
[c]Refer to existing standard sheets for dowel bar spacing. Dowel bar length equals 450 mm (18 in.).
[d]500 million Equivalent Single Axle Loads (ESALs) is the practical limit for traffic volume.

Table 2. Tie bar length.

Tie Bar Diameter		Interior Travel Lanes				1.2 m (4 ft) Shoulder		2.4 m (8 ft) Shoulder	
		Grade 40 Steel		Grade 60 Steel		Grade 40 or 60 Steel			
mm	in.	mm	in.	mm	in.	mm	in.	m	in.
13	½	550	22	800	32	450	18	450	18
16	⅝	675	27	975	39	450	18	500	20
19	¾	800	32	1150	46	450	18	550	22

Table 3. Number of tie bars per slab (Grade 40 Steel).

Slab		Distance To The Nearest Free Longitudinal Edge																	
		1.2 m (4 ft)			2.4 m (8 ft)			5.0 m (16 ft)			6.7 m (22 ft)			8.5 m (28 ft)			10.4 m (34 ft)		
		Tie Bar Diameter in mm (in.)																	
Thickness	Length	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)
200 mm (8 in.)	5.0 m (16 ft)	4	4	4	5	4	4	11	7	5	15	9	7		13	8		15	10
225 mm (9 in.)	5.0 m (16 ft)	4	4	4	6	4	4	12	8	5	17	10	7		13	10		17	12
250 mm (10 in.)	5.0 m (16 ft)	4	4	4	7	4	4	13	9	6		12	8		15	11			13
275 mm (11 in.)	5.5 m (18 ft)	5	5	5	8	5	5	16	10	7		15	10		18	13			16
300 mm (12 in.)	5.5 m (18 ft)		5	5		6	5		11	8		16	11			14			17
325 mm (13 in.)	5.5 m (18 ft)		5	5		6	5		12	9		17	12			16			18

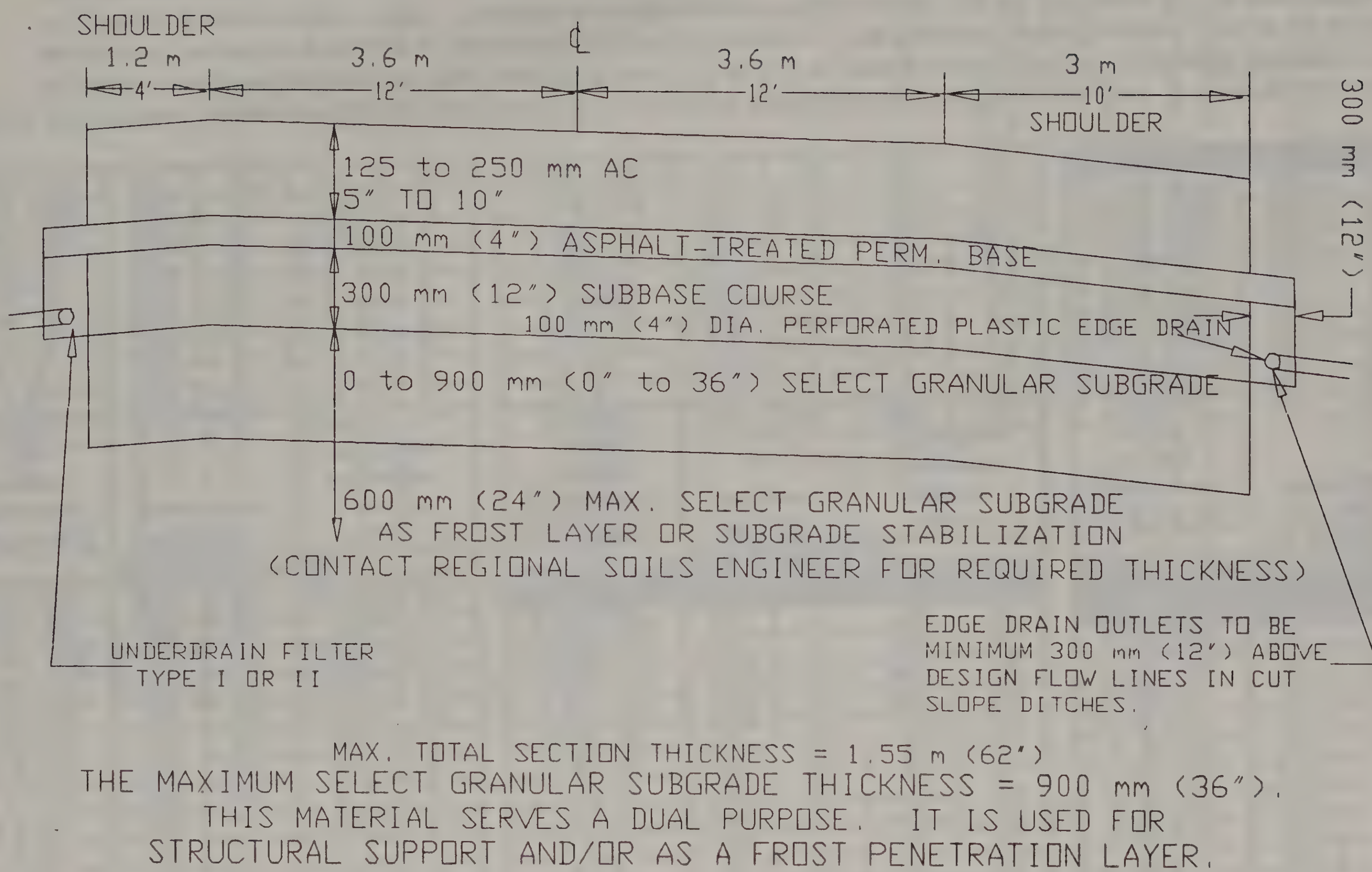
Notes: Steel grade and tie bar diameter to be determined by designer. For four tie bars, locate one 0.6 m (2 ft) from each of the two nearest transverse joints. For five tie bars or more, locate one 0.3 m (1 ft) from each of the two nearest transverse joints, and distribute the remaining bars at uniform spacing between the first two bars.

Table 4. Number of tie bars per slab (Grade 60 Steel).

Slab		Distance To The Nearest Free Longitudinal Edge																	
		1.2 m (4 ft)			2.4 m (8 ft)			5.0 m (16 ft)			6.7 m (22 ft)			8.5 m (28 ft)			10.4 m (34 ft)		
		Tie Bar Diameter in mm (in.)																	
Thickness	Length	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)	13 (½)	16 (⅝)	19 (¾)
200 mm (8 in.)	5.0 m (16 ft)	4	4	4	4	4	4	7	5	4	10	6	4	13	8	6	15	10	7
225 mm (9 in.)	5.0 m (16 ft)	4	4	4	4	4	4	8	5	4	11	7	5	14	9	6		11	8
250 mm (10 in.)	5.0 m (16 ft)	4	4	4	5	4	4	9	6	4	13	8	6	15	10	7		13	9
275 mm (11 in.)	5.5 m (18 ft)	5	5	5	6	5	5	11	7	5	14	9	7		12	8		15	10
300 mm (12 in.)	5.5 m (18 ft)		5	5		5	5		8	5		10	7		14	9		17	11
325 mm (13 in.)	5.5 m (18 ft)		5	5		5	5		8	6		11	8		15	10		18	12

Notes: Steel grade and tie bar diameter to be determined by designer. For four tie bars, locate one 0.6 m (2 ft) from each of the two nearest transverse joints. For five tie bars or more, locate one 0.3 m (1 ft) from each of the two nearest transverse joints, and distribute the remaining bars at uniform spacing between the first two bars.

Figure 2. Typical flexible pavement cross-section.



Please contact Main Office Soil Mechanics Bureau through the Regional Soils Engineer for desired typical sections deviating in the vertical from what is shown above.

Table 5. Flexible pavement design.

Mr = 28 MPa (4 ksi)				
80 kN (18 kip) ESALs over Design Life	AC Layer Thickness		Select Granular Subgrade Thickness	
millions	mm	in.	mm	in.
< 1	125	5	0	0
1 - 2	150	6	0	0
> 2 - 4	175	7	0	0
> 4 - 8	200	8	0	0
> 8 - 13	225	9	0	0
> 13 - 23	250	10	0	0
> 23 - 45	250	10	150	6
> 45 - 80	250	10	300	12
> 80 - 140	250	10	450	18
> 140 - 240	250	10	600	24
> 240 - 400	250	10	750	30
> 400 - 500	250	10	900	36

Mr = 32 MPa (5 ksi)				
80 kN (18 kip) ESALs over Design Life	AC Layer Thickness		Select Granular Subgrade Thickness	
millions	mm	in.	mm	in.
< 2	125	5	0	0
2 - 4	150	6	0	0
> 4 - 7	175	7	0	0
> 7 - 13	200	8	0	0
> 13 - 23	225	9	0	0
> 23 - 40	250	10	0	0
> 40 - 70	250	10	150	6
> 70 - 130	250	10	300	12
> 130 - 235	250	10	450	18
> 235 - 400	250	10	600	24
> 400 - 500	250	10	750	30

Mr = 41 MPa (6 ksi)				
80 kN (18 kip) ESALs over Design Life	AC Layer Thickness		Select Granular Subgrade Thickness	
millions	mm	in.	mm	in.
< 3	125	5	0	0
3 - 6	150	6	0	0
> 6 - 11	175	7	0	0
> 11 - 20	200	8	0	0
> 20 - 35	225	9	0	0
> 35 - 60	250	10	0	0
> 60 - 110	250	10	150	6
> 110 - 200	250	10	300	12
> 200 - 360	250	10	450	18
> 360 - 500	250	10	600	24

Mr = 48 MPa (7 ksi)				
80 kN (18 kip) ESALs over Design Life	AC Layer Thickness		Select Granular Subgrade Thickness	
millions	mm	in.	mm	in.
< 4	125	5	0	0
4 - 8	150	6	0	0
> 8 - 16	175	7	0	0
> 16 - 30	200	8	0	0
> 30 - 50	225	9	0	0
> 50 - 85	250	10	0	0
> 85 - 160	250	10	150	6
> 160 - 290	250	10	300	12
> 290 - 500	250	10	450	18

Mr = 55 MPa (8 ksi)				
80 kN (18 kip) ESALs over Design Life	AC Layer Thickness		Select Granular Subgrade Thickness	
millions	mm	in.	mm	in.
< 6	125	5	0	0
6 - 12	150	6	0	0
> 12 - 20	175	7	0	0
> 20 - 40	200	8	0	0
> 40 - 65	225	9	0	0
> 65 - 115	250	10	0	0
> 115 - 215	250	10	150	6
> 215 - 395	250	10	300	12
> 395 - 500	250	10	450	18

Mr = 62 MPa (9 ksi)				
80 kN (18 kip) ESALs over Design Life	AC Layer Thickness		Select Granular Subgrade Thickness	
millions	mm	in.	mm	in.
< 8	125	5	0	0
8 - 15	150	6	0	0
> 15 - 30	175	7	0	0
> 30 - 50	200	8	0	0
> 50 - 90	225	9	0	0
> 90 - 150	250	10	0	0
> 150 - 280	250	10	150	6
> 280 - 500	250	10	300	12

Notes: 500 million Equivalent Single Axle Loads (ESALs) is the practical limit for traffic volume. A 100-mm (4-in.) layer of asphalt-treated permeable base over 300 mm (12 in.) of subbase course should be placed between the AC layer and the select granular subgrade for all flexible designs. The Regional Soils Engineer should be consulted for proper determination of M_r. Guidelines for the determination of M_r will be prepared by the Main Office Soil Mechanics Bureau. Contact the Regional Soils Engineer for conditions where it would be difficult to provide the required subbase course and/or select granular subgrade layer thicknesses. The Soil Mechanics Bureau is available for consultation through the Regional Soils Engineer where options are requested. Refer to p. 25 for definition of M_r.

III. DISCUSSION

A. Rigid Pavements

1. Thickness Design Procedure

The basic AASHTO design equation for rigid pavement structures has been modified to take into account NYSDOT experience, which indicates that pavements in New York State last longer than would be predicted from the AASHTO design equation. The adjustment has specifically been made to structural carrying capacity of the pavement or pavement thickness. The revised AASHTO design equation for rigid pavement structures follows [this equation is valid only for the U.S. Customary System (USCS); as this manual was being prepared, the updated equation for SI units was yet to be determined]:

$$\log_{10}(W_{18}) = [\, Z_R \times S_o \,] + \left[0.5 \times \left(1 + \frac{\log_{10}(D + 0.86)}{0.068} \right) \right] - 0.06$$

$$+ \frac{\log_{10}\left(\dfrac{P_o - P_t}{4.5 - 1.5} \right)}{1 + \dfrac{4.31 \times 10^6}{(D + 1.17)^{8.46}}} + [\, 4.22 - (0.32 \times P_t) \,] \qquad \textbf{(1)}$$

$$\times \log_{10} \left[\frac{S_c' \times C_d \times (D^{0.75} - 1)}{215.63 \times J \times \left(D^{0.75} - \dfrac{16.2}{\left(\dfrac{E_c}{k} \right)^{0.25}} \right)} \right]$$

where W_{18} = predicted number of 80-kN (18-kip) Equivalent Single Axle Load (ESAL) applications over the design life (Appendix A),

R = reliability of the pavement structure,

Z_R = standard normal deviate (this factor is a measure of how likely a pavement is to fail within the design period, and is associated with level of reliability). The following table gives Z_R values associated with levels of reliability:

R^a	Z_R
50%	0.000
60%	-0.253
70%	-0.524
75%	-0.674
80%	-0.841
85%	-1.037
90%	-1.282[b]
95%	-1.645
99%	-2.327

[a]See p. 15 for explanation of R.
[b]Value used in this manual.

S_o = standard deviation,

D = rigid pavement slab thickness in inches (this is the variable for which the equation must be solved),

P_o = initial design serviceability index,

P_t = terminal serviceability index,

S_c' = 28-day concrete modulus of rupture in psi,

C_d = drainage coefficient,

J = load transfer coefficient,

E_c = concrete modulus of elasticity in psi, and

k = effective modulus of subgrade reaction in pci.

A more detailed explanation follows of input parameters in the AASHTO thickness design equation (listed in the order they appear in that equation), and how they affect overall thickness design. Design Table 1 is based on these values, assigned as input parameters in the revised AASHTO design equation.

Traffic Loading (W_{18})

Most pavements are designed to withstand repeated applications of traffic load. This loading, in terms of the revised AASHTO design equation, is expressed in terms of total 80-kN (18-kip) Equivalent Single Axle Loads (ESALs) generated over the design life of the pavement structure. Appendix A gives a full discussion of ESALs along with procedures used to predict total traffic loading. This is the major input parameter in Design Table 1 in Chapter II.

Reliability of the Pavement Structure (R)

AASHTO *(1)* defines R as follows:

> *The reliability of a pavement design-performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period.*

This probability that a pavement will last through its design life is given as a percentage. A reliability level of 90 percent is used here.

Standard Deviation (S_o)

This factor is the combined standard error of the traffic and performance predictions. The AASHTO *Design Guide* recommends a range of 0.30 to 0.40 for rigid pavement design. Due to lack of experience with this factor at this time and its relative insensitivity in overall thickness design, a midrange value of 0.35 is used in this manual for rigid pavements. Appendix EE, page 22, of the AASHTO *Design Guide* should be consulted for further details about this parameter.

Initial Design Serviceability Index (P_o)

This index is an estimate of what the Present Serviceability Index (PSI) will be immediately after construction. The scale for PSI ranges from 0 through 5, with 5 representing the highest index of serviceability or what might be called a "perfect" road. Roughness is the dominant factor in estimating a pavement's PSI, and thus controls the pavement's life cycle. Initial serviceability index values for the AASHO Road Test conditions were 4.2 for flexible pavements and 4.5 for rigid pavements. Due to technological advances in paving methods and equipment since then and for simplicity, a value of 4.5 is used here.

Terminal Serviceability Index (P_t)

This index is the lowest acceptable PSI level before resurfacing or reconstruction is required. The scale for this factor is the same as for the initial serviceability index. According to the AASHTO *Design Guide*, major factors influencing loss of a pavement's serviceability are traffic, age, and environment. The following table was developed from studies associated with the AASHO Road Test:

Terminal Serviceability Level	Percent of People Stating "Unacceptable"
3.0	12
2.5	55
2.0	85

Based on this table and NYSDOT's experience with sensitivity of this parameter in the AASHTO design equation, a value of 2.5 is used here.

Concrete Modulus of Rupture (S_c')

This modulus of flexural strength of the concrete has been researched and reported by the NYSDOT Materials Bureau *(5)*. Based on their findings, a value of 4.14-MPa (0.60-ksi) is used for this variable, provided a concrete mixture with a compressive strength of 28 MPa (4.0 ksi) is used. Overall thickness of the rigid pavement slab is sensitive to this variable. If a concrete mixture other than Class C is to be used, the NYSDOT Materials Bureau should be consulted to ensure that the proper value for this parameter is used.

Drainage Coefficient (C_d)

This coefficient is used to account for the expected level of drainage a rigid pavement structure is to encounter over its life. The value depends on quality of drainage and percentage of time during the year that the pavement structure is subjected to moisture levels reaching saturation. The effect on rigid pavement slab thickness of the drainage coefficient parameter in the revised AASHTO design equation is that better drainage will produce a thinner slab and improved pavement support. Based on the prevailing philosophy that proper drainage of the pavement structure is an important factor in overall design, NYSDOT will now use a treated permeable base for all new and reconstructed rigid pavement structures. A C_d value of 1.25 for treated permeable base is used in this manual, based on information in the AASHTO *Design Guide*.

Load Transfer Coefficient (J)

This coefficient is used to account for a rigid pavement's ability to transfer load across joints in the pavement structure, and is determined by the type of shoulder used in the design (tied-PCC or AC). Current NYSDOT policy for rigid pavement design includes steel dowels at the transverse joints. It is recommended that this practice be continued. This manual requires that all new rigid pavement designs contain tied-PCC shoulders rather than the AC shoulders used in the past. The AASHTO *Design Guide* recommends that 2.7 be used as the J-value, depending on the shoulder material. NYSDOT concurs with use of this value. It should be noted that pavement thickness is sensitive to changes in this parameter. A jointed concrete pavement with tied PCC shoulders allows a thinner pavement section than if AC shoulders were used, due to lower stress at the longitudinal joint for tied PCC shoulders. Shoulder width does not affect the value of the load transfer coefficient.

Concrete Modulus of Elasticity (E_c)

The NYSDOT Materials Bureau has recommended using a value of 25 GPa (3600 ksi). It should be noted that this variable has little effect on overall pavement thickness design and is thus considered an insensitive variable.

Effective Modulus of Subgrade Reaction (k)

This modulus or composite k-value, given in megapascals per meter (MPa/m) (pounds per cubic inch or pci), is the combined support value for the existing natural soil and the subbase and/or base material. The NYSDOT Soil Mechanics Bureau recommends using the following value based on material properties of the base and subbase, soil resilient-modulus studies, and experiences of other state agencies: an effective k-value of 54 MPa/m (200 pci), when the material beneath the pavement slab is a treated permeable base over subbase course(s) over natural soil. It is important to note that the k-value is deemed insensitive in the overall AASHTO thickness design equation for rigid pavements.

2. Minimum Thickness Standards

A 200-mm (8-in.) rigid pavement slab over 100 mm (4 in.) of an optional asphalt- or cement-treated permeable base, over a 300-mm (12-in.) subbase course used as a filter layer, will be the minimum pavement section for all new and reconstructed rigid pavements. The Regional Soils Engineer should be contacted when existing conditions make it difficult to provide this minimum section. The Soil Mechanics Bureau is available for consultation through the Regional Soils Engineer for requested variations in thickness standards.

3. Slab Length

Slab length in jointed unreinforced rigid pavements critically affects crack control, slab curl, and joint movement *(6)*. Several studies have found strong interactions among slab length, slab thickness, effective modulus of subgrade reaction (k), and slab stiffness. The criterion is based on the L/ℓ ratio, where L = slab length, and ℓ = radius of relative stiffness [as defined by Westergaard *(7)*]. The L/ℓ ratio considers this interaction, and thus has been adopted in this manual. Slab lengths recommended here will minimize the potential for transverse cracking due to shrinkage, temperature differential, and traffic loads. The following limits on L/ℓ ratios were used to develop Table 6:

Base Type	Maximum L/ℓ Ratio
Cement-treated permeable base	6.1
Asphalt-treated permeable base	6.8

In addition to these limits, the following design table was developed for Class C concrete with compressive strength (f'_c) of 28 MPa (4.0 ksi) and a modulus of elasticity (E_c) of 25 GPa (3600 ksi):

Table 6. Maximum-slab-length design.

Slab Thickness		Slab Length*	
mm	in.	m	ft
200	8	5	16
225	9	5	16
250	10	5	16
275	11	5.5	18
300	12	5.5	18
325	13	5.5	18

*For either asphalt- or cement-treated permeable base.

4. <u>Dowel Size</u>

New York State experience *(6)* has indicated that use of dowels is essential to retard faulting when PCC pavement is subjected to heavy traffic loading. Dowels transfer loads applied by traffic from one slab to the next, and minimize vertical deflection at the joint. Insufficient joint load transfer increases the potential for faulting and pumping by allowing differential vertical deflections.

Table 7 for dowel bar design was developed using a mechanistic-empirical approach, with a fatigue model relating pavement performance to a mechanistic parameter: maximum concrete bearing stress (σ_{max}). This faulting model, given by Eq. 2 (input in USCS units), was formulated using data from the AASHO Road Test database developed by ERES Consultants Inc. for FHWA, and the *Concrete Pavement Evaluation System (COPES)* developed by M.I. Darter for the University of Illinois *(8)*. These data include various pavement characteristics, environmental conditions, and traffic conditions. Concrete bearing stresses significantly depend on dowel diameter, elastic modulus of the concrete, and applied load. Since E_c and the applied load are fixed in this analysis, σ_{max} becomes a function of dowel bar diameter only and thus can be computed for different dowel bar diameters.

$$FAULT = ESALs^{a} \times [(b \times \sigma_{max}^{c}) + (d \times k^{e}) + (f \times TS)] \quad (2)$$

where FAULT = mean transverse joint faulting in cm (in.),

ESALs = cumulative 80-kN (18-kip) ESALs (millions),

σ_{max} = maximum concrete bearing stress in MPa (ksi),

k = modulus of subgrade reaction in MPa/m (pci), and

TS = shoulder type (0 if asphalt, 1 if tied PCC)

The Eq. 2 estimated coefficients are as follows:

a = 0.6

b = 0.00334

c = 2

d = 60.228

e = -1.809

f = -0.0074

The recommended values given in Table 7 were determined using Eq. 2, which relates a predicted fault to dowel size and fatigue loading in terms of ESALs. Dowels must be spaced every 300 mm ± 10 mm (12 in. ± ½ in.) on center, with the first and last dowels placed 150 mm (6 in.) from the pavement edge (refer to NYSDOT standard specifications). A final requirement is that dowels be epoxy-coated (refer to NYSDOT standard specifications).

Table 7. Dowel bar design.

80-kN (18-kip) ESALs	Dowel Bar Diameter		Maximum Concrete Bearing Stress	
millions	mm	in.	MPa	ksi
< 35	32	1¼	15	2.2
35 - 65	32	1¼	13	1.9
> 65 - 125	32	1¼	11	1.6
> 125 - 220	35	1⅜	9.7	1.4
> 220 - 380	38	1½	9.0	1.3
> 380 - 500*	41	1⅝	8.3	1.2

*500 million ESALs is the practical limit for traffic volume.

5. Tie Bars

These are deformed steel bars used along longitudinal joints to connect one lane to another or to a rigid shoulder. They are designed to overcome the tensile forces associated with subgrade drag, and are not designed as load transfer devices. The first step in designing tie bars is determining the area of steel A_s required per unit length of slab length to resist subgrade drag forces. This is accomplished through use of Eq. 3:

$$A_s \text{ (in SI units)} = \frac{10 \times D_{fe} \times f \times W \times h}{f_s} \qquad \textbf{(3a)}$$

or

$$A_s \text{ (in USCS units)} = \frac{D_{fe} \times f \times W \times h}{12 \times f_s} \qquad \textbf{(3b)}$$

where A_s = area of steel in cm^2/m (in^2/ft),

D_{fe} = distance to the closest free edge in m (ft),

f = coefficient of resistance, 1.5, and

W = unit weight of the concrete, 24.0 kN/m^3 (150 pcf),

h = slab thickness in cm (in.), and

f_s = allowable stress in the steel in MPa (psi) taken as ⅔ yield strength [f_y = 415 MPa (60 ksi) or f_y = 275 MPa (40 ksi)].

Once the area of steel required is determined, tie bar spacing for different bar sizes can be computed using Eq. 4:

$$d \text{ (in SI units)} = \frac{1000 \times A_b}{A_s} \qquad \textbf{(4a)}$$

or

$$d \text{ (in USCS units)} = \frac{12 \times A_b}{A_s} \qquad \textbf{(4b)}$$

where d = tie bar spacing in mm (in.), and

A_b = area of bar to be used in cm^2 (in^2).

Refer to Tables 3 and 4 in Chapter II for the solution to Eqs. 3 and 4.

Vertical placement of tie bars should be at pavement mid-depth. All tie bars must be epoxy-coated in accordance with NYSDOT standard specifications.

B. Flexible Pavements

1. Thickness Design Procedure

Design of flexible pavements according to the AASHTO *Design Guide* is a two-step procedure. The first step is to determine a structural number (SN) for the pavement section, followed by determination of the pavement thickness. Table 5 in Chapter II is based on assigned values for the input parameters. The basic AASHTO design equation for flexible pavement structures follows (this equation is valid only for USCS units; as this manual was being prepared, the updated equation for SI units was yet to be determined):

$$\log_{10}(W_{18}) = [\, Z_R \times S_o \,] + [\, 9.36 \times \log_{10}(SN + 1) \,] - 0.20 + \frac{\log_{10}\left[\dfrac{P_o - P_t}{4.2 - 1.5}\right]}{0.40 + \dfrac{1094}{(SN + 1)^{5.19}}} + [\, 2.32 \times \log_{10}(M_r) \,] - 8.07 \qquad (5)$$

where W_{18} = predicted number of 80-kN (18-kip) Equivalent Single Axle Load (ESAL) applications over the design life (Appendix A),

R = reliability of the pavement structure,

Z_R = standard normal deviate; this factor is a measure of how likely a pavement is to fail within the design period, and is associated with the level of reliability. The following table gives Z_R values associated with levels of reliability:

R[a]	Z_R
50%	0.000
60%	-0.253
70%	-0.524
75%	-0.674
80%	-0.841
85%	-1.037
90%	-1.282[b]
95%	-1.645
99%	-2.327

[a]See p. 24 for explanation of R.
[b]Value used in this manual.

S_o = standard deviation,

SN = design structural number (the equation must be solved for this variable in order to complete Step 1 of the flexible pavement design procedure),

P_o = initial design serviceability index,

P_t = terminal serviceability index, and

M_r = effective roadbed soil resilient modulus in psi.

The second step in the flexible pavement design procedure is to solve the following equation:

$$SN = a_1D_1 + a_2D_2 + a_iD_im_i \qquad (6)$$

where SN = structural number determined in the first step of the design procedure,

a_1 = structural coefficient of the AC layer (value to be used is shown on p. 25),

D_1 = thickness of the asphalt concrete courses (top, binder, and base); this is the variable for which the equation must be solved,

a_2 = structural coefficient of the asphalt-treated permeable base (value to be used is shown on p. 25),

D_2 = thickness of the asphalt-treated permeable base,

a_i = structural coefficient of the i^{th} layer [subbase course(s)] (values to be used are shown on p. 25),

D_i = thickness of the i^{th} layer of the pavement structure [subbase course(s)], and

m_i = drainage coefficient of the i^{th} layer [subbase course(s)] (values to be used are shown on p.26).

A more detailed explanation of input parameters in the AASHTO thickness design equation follows (again listed in the order they appear in the equation), as well as how they affect overall thickness design. Thickness Design Table 5 in Chapter II is based on the values used as input parameters.

Traffic Loading (W_{18})

Most pavements are designed to withstand repeated applications of traffic load. This loading, in terms of the AASHTO design equation, is expressed as the total 80-kN (18-kip) Equivalent Single Axle Loads (ESALs) generated over the design life of the pavement structure. A full discussion along with the procedures used to predict total traffic loading is given in Appendix A. This is the major input parameter for Design Table 5 in Chapter II.

Reliability of the Pavement Structure (R)

This is defined by AASHTO *(1)* as:

> *The reliability of a pavement design-performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period.*

This probability that the pavement will last through its design life is given as a percentage. A reliability level of 90 percent is used in this manual.

Standard Deviation (S_o)

This is the combined standard error of the traffic and performance predictions. For flexible pavement design the AASHTO *Design Guide* recommends a range of 0.40 to 0.50 for this variable. Due to lack of experience with this factor at this time and its relative insensitivity in overall thickness design, a midrange value of 0.45 is used in this manual for flexible pavement design. The AASHTO Guide (Appendix EE, p. 22) should be consulted for further details about this parameter.

Initial Design Serviceability Index (P_o)

This is an estimation of what the Present Serviceability Index (PSI) will be immediately after construction. The scale ranges from 0 through 5, with 5 representing the highest index of serviceability or a "perfect" road. Roughness is the dominant factor in estimating a pavement's PSI and thus will control its life cycle. The initial serviceability index values for the AASHO Road Test conditions were 4.2 for flexible pavements and 4.5 for rigid pavements. Due to technological advances in paving methods and equipment since then and for simplicity, a value of 4.5 is used.

Terminal Serviceability Index (P_t)

This is the lowest acceptable PSI level before resurfacing or reconstruction is required. Its scale is the same as that for the Initial Serviceability Index. According

to the AASHTO *Design Guide*, the major factors influencing loss of serviceability of a pavement are traffic, age, and environment. Based on recommendations in the AASHTO *Design Guide* and experience with the sensitivity of this parameter in the AASHTO design equation, a value of 2.5 is used.

Effective Roadbed Soil Resilient Modulus (M_r)

This is the definitive material property used in the AASHTO *Design Guide* to characterize roadbed soils for purposes of pavement design. It is a measure of the elastic property of soil that recognizes certain nonlinear characteristics. According to the AASHTO *Design Guide* and preliminary studies conducted by the NYSDOT Soil Mechanics Bureau, a range of 28 to 62 MPa (4.0 to 9.0 ksi) is recommended for this variable, with the low value representing a clay and the high a gravel. The Regional Soils Engineer should be consulted in determining this variable.

Structural Layer Coefficients (a_i)

This is a dimensionless number assigned to each layer of the flexible pavement section, based on strength properties of the material in each layer. Extensive research has produced the following values used in this manual:

Material	Structural Layer Coefficient
Asphalt Concrete	0.42[a]
Asphalt-Treated Permeable Base	0.23[b]
Subbase Course	0.12[a]
Select Granular Subgrade	0.10[a]

[a]From Ref. 3.
[b]From Ref. 9.

Drainage Coefficient (m_i)

This accounts for the expected level of drainage in the untreated base and subbase layers of the flexible pavement structure over its life. The drainage coefficient value for each unbound layer depends on quality of drainage and percentage of time during the year that the pavement structure is subjected to moisture levels reaching saturation. The effect of the drainage coefficient on pavement thickness, in the AASHTO design equation, is that better drainage will produce thinner AC layers. Improved drainage improves support conditions and should influence pavement performance. It should be noted that the AASHTO design

equation does not allow input of a drainage factor for bound layers, such as the AC course and a treated permeable base. Adding a treated permeable drainage layer thus would have only the structural effect of an additional AC layer, but a treated drainage layer will greatly increase the life of flexible pavements, as well as decreasing the amount of future maintenance. The following values, based on information in the AASHTO *Design Guide*, should be used for this variable:

Material	Drainage Coefficient
Subbase Course	0.9
Select Granular Subgrade	0.9

2. Minimum Thickness Standards

For all new and reconstructed flexible pavement structures, the minimum pavement section will be 125 mm (5 in.) of asphalt concrete over 100 mm (4 in.) of asphalt-treated permeable base, over 300 mm (12 in.) of subbase course used as a filter layer. Also, thickness of the AC layer should not exceed 250 mm (10 in.), but rather additional select granular subgrade should be added in 150-mm (6-in.) lifts to achieve the necessary structural capacity. The Regional Soils Engineer should be contacted when existing conditions make it difficult to provide this minimum section. The Soil Mechanics Bureau is available for consultation through the Regional Soils Engineer for requested variations in thickness standards.

C. Maintenance of the Drainage System

The new NYSDOT design philosophy calls for improved methods of pavement drainage, making possible the longer pavement design life of 50 years. Use of a treated permeable drainage layer, along with continuous edge drains outletting at intervals of about 76 m (250 ft) ±, is the method being adopted for improved pavement drainage. However, for this system to function properly, an improved maintenance schedule must also be adopted. If the edge drain system is clogged and fails to operate as designed, the results can be worse than not using a permeable base. Rapid loss of serviceability is possible due to water trapped beneath the pavement. A concrete headwall should be considered, with a rodent screen at outlets of the drainage system. Inclusion of a headwall, flush with the embankment slope, will simplify both locating and cleaning the edge drain system. See the proposed standard sheets for details of the headwall and rodent screen design. It should be noted that maintenance of the drainage system is a future periodic expense and should be so treated in any life-cycle-cost analyses. Routine maintenance should include the following as a minimum:

1. Provide outlet delineators, reference markers, or headwalls with rodent screens so outlets can be found.

2. Inspect and clean outlet pipes as necessary at least every 5 years.

3. Inspect and ascertain the need to flush or jet rod the edge drain system at least every 5 years. To accomplish this task, outlet pipes should be connected to edge drains with curved connector pipes (see proposed standard sheets for details).

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APPENDIX A

TRAFFIC PREDICTION

Table A-1. FHWA Vehicle Classifications

FHWA Vehicle Classification	Description
1	Motorcycles
2	Passenger cars
3	Other two-axle, four-tire single-unit vehicles
4	Buses
5	Two-axle, six-tire single-unit trucks
6	Three-axle single-unit trucks
7	Four-or-more-axle single-unit trucks
8	Four-or-less-axle single-trailer trucks
9	Five-axle single-trailer trucks
10	Six-or-more-axle single-trailer trucks
11	Five-or-less-axle multi-trailer trucks
12	Six-axle multi-trailer trucks
13	Seven-or-more-axle multi-trailer trucks

APPENDIX A. Traffic Prediction

Traffic prediction is a critical input parameter for the AASHTO thickness design equations, due to its sensitivity. Traffic on a pavement structure includes numerous types of vehicles with varying weights and axle configurations. Anticipated loads applied for a pavement's entire design life must be converted to a single uniform factor to be incorporated into the AASHTO design equations. This factor is known as 80-kN (18-kip) Equivalent Single Axle Loads (ESALs). Except for the initial performance period of 50 years, the remaining traffic data should be obtained from NYSDOT regional planning offices for each specific project.

AASHTO suggests two methods (termed "simple" and "rigorous") for obtaining an ESAL calculation for design of a flexible or rigid pavement structure. For either method, inputs (defined in the next section of this Appendix) include 1) initial performance period, 2) initial two-way average annual daily traffic (AADT), 3) number of lanes in one direction, 4) percent of all trucks in the design direction, and 5) percent of all trucks in the design lane.

For the first or "simple" ESAL calculation procedure, additional inputs (also defined in the next section of this Appendix) include 1) percent of heavy trucks (FHWA Class 5 or higher, as shown in Table A-1), 2) average initial truck factor, 3) annual truck-weight growth rate, 4) annual truck-volume growth rate, and 5) whether growth is simple or compound. This method assumes an average truck factor taking into account all trucks using the pavement structure (FHWA Vehicle Classes 5 through 13). Thus, it may not produce results as accurate as the "rigorous" method, depending on distribution of truck axle weights. Since the contribution of vehicles in Classes 1 through 4 is insignificant for the overall ESAL count, this method does not take them into account.

The second or "rigorous" ESAL calculation procedure requires the percent of total AADT for each FHWA vehicle classification. Since this method divides total traffic into 13 vehicle classifications and applies specific truck factors to each class, it is a more precise calculation of total ESALs to which the pavement structure will be subjected than the potential ambiguity of the "simple" method. However, it should be noted that at present the Department does not have the traffic count database or sufficient resources to implement the "rigorous" ESAL calculation procedure. Currently, the Data Services Bureau and the Urban and Corridor Planning Bureau are investigating a simple way for designers to determine ESAL counts based on traffic data from six existing weigh-in-motion stations and many more (100+) planned statewide. Meanwhile, it is recommended that regional offices consult these Bureaus for the most appropriate methods of estimating ESAL counts on a project-by-project basis.

1. Inputs for Calculation

Initial Performance Period

As defined by AASHTO, this is the design life of the pavement structure in years (in this case 50 years). This should not be confused with the service lives of reconstructed pavements as explained in the *Pavement Rehabilitation Manual, Volume II, Treatment Selection* (10). For example, a newly constructed AC pavement has a service life of 15 years. At that time, an additional overlay may be required. Although the service life of the pavement (15 years) has been reached, the design life and load-carrying capacity of the entire pavement structure have not been reached.

Initial Two-Way Average Annual Daily Traffic (AADT)

This is the anticipated (forecast) 24-hour two-way vehicle count for a new or reconstructed pavement structure when initially opened to traffic. The count is given in vehicles per day and includes all FHWA vehicle classifications.

Percent Trucks in Design Direction

This is a directional distribution factor applied to the two-way AADT to account for any variations in truck traffic volumes or weights by direction. Under normal circumstances, the directional distribution factor is about 50 percent, but in special cases where one direction of travel has a larger volume or heavier traffic, that should be considered the design direction.

Percent Trucks in Design Lane

On a multi-lane roadway, truck traffic will be found in all lanes, but in designing a pavement structure the lane with most truck traffic is of vital interest and is called the "design lane." "Percent trucks in the design lane" is a lane distribution factor accounting for the percentage of trucks in that lane. The AASHTO *Design Guide* recommends the following design-lane percent-truck distribution factors:

Number Of Lanes In Each Direction	Percent Of Trucks In Design Lane
1	100
2	80-100
3	60-80
4	50-75

Percent Heavy Trucks (FHWA Class 5 or Greater)

This is the percentage of vehicles in the average daily traffic flow that are in FHWA Class 5 or higher.

Average Initial Truck Factor (ESALs/Truck)

This is a representation of the number of 80-kN (18-kip) ESAL applications caused by a single passage of a given truck. For the "simple" ESAL calculation method, a single average truck factor is used for FHWA Vehicle Classes 5 through 13 (Classes 1 through 4 are ignored). For the "rigorous" method, a truck factor is used for each FHWA vehicle class. Tables A-2 and A-3 illustrate typical examples of truck factors that may be used in the ESAL count calculation. In Table A-2, it should be noted that vehicles in FHWA Classes 1 through 4 are not considered in the "simple" calculation method. These values probably will be updated regularly as more weigh-in-motion data are collected and compiled. The values in Table A-3 will also probably be updated regularly.

Table A-2. Truck Equivalency Factor For "Simple" ESAL Calculation Method.

FHWA Vehicle Classifications	Truck Equivalency Factor *
5 - 13	1.7

* Truck Equivalency Factors will be different for rigid and flexible pavements for the same traffic loadings. Consult the Data Services Bureau for proper value to use on a project-by-project basis.

Table A-3. Truck Equivalency Factors For "Rigorous" ESAL Calculation Method.

FHWA Vehicle Classification	Truck Equivalency Factor *
1	0.00002
2	0.0005
3	0.01
4	0.9
5	0.3
6	1.9
7	5.4
8	0.8
9	2.4
10	5.5
11	2.3
12	2.0
13	6.4

* Truck Equivalency Factors will be different for rigid and flexible pavements for the same traffic loadings. Consult the Data Services Bureau for proper values to use on a project-by-project basis.

Annual Truck Weight Growth Rate

Just as the number of vehicles using a roadway tends to increase with time, so may their weights increase. "Annual truck factor growth rate" is an input value accounting for the increase in truck weights over time. It is expressed as a percentage and typically ranges from 0 to 4 percent per year. It can cause a dramatic increase in growth of ESALs over the life of the pavement structure.

Annual Truck Volume Growth Rate

Expressed as a percent, this is used to specify the anticipated annual growth rate of the truck traffic volume over a pavement's design life, and may be simple or compound.

Simple Growth Rate

This is applied to an Average Annual Daily Traffic (AADT) value. For example, if AADT for the first year is 5000 with a simple growth rate of 2 percent, it is estimated that each year AADT will grow by 100 vehicles. Table A-4 illustrates simple traffic volume for the first 10 years of the 50-year design life.

Table A-4. Simple Traffic Growth Illustration

Year	Beginning AADT	Growth	Final AADT
1	-	-	5000
2	5000	100	5100
3	5100	100	5200
4	5200	100	5300
5	5300	100	5400
6	5400	100	5500
7	5500	100	5600
8	5600	100	5700
9	5700	100	5800
10	5800	100	5900

Total = 54,500

Compound Growth Rate

Applied to an AADT, this is an estimate of the annual percent growth in traffic volume. Compounding the growth rate means that growth for any given year is applied to the volume for the preceding year. The following formula is used to calculate compound growth:

$$GF = (1 + i)^n \tag{7}$$

where GF = a growth factor multiplied by the initial value,

i = annual growth rate, and

n = period of interest, in years.

Table A-5 illustrates compound growth of traffic for the first 10 years of the 50-year design life.

Table A-5. Compound Traffic Growth Illustration

Year	Initial AADT	Growth Rate	Growth	Final AADT
1	-	-	-	5000
2	5000	0.02	100	5100
3	5100	0.02	102	5202
4	5202	0.02	104	5306
5	5306	0.02	106	5412
6	5412	0.02	108	5520
7	5520	0.02	110	5630
8	5630	0.02	113	5743
9	5743	0.02	115	5858
10	5858	0.02	117	5975

Total = 54,746

2. "Simple" ESAL Calculation

Table A-6 should be used as a work sheet to calculate total anticipated 80-kN (18-kip) ESAL count applications for a simple traffic-volume growth rate. Table A-7 should be used as a work sheet to calculate total anticipated ESAL count applications for a compound-traffic volume growth rate.

Table A-6. 80-kN (18-kip) ESAL calculation work sheet for the "simple" method with simple traffic growth.

Input Parameters:

1. Design Life = ____________
2. Initial AADT = ____________
3. Percent Heavy Truck (Class 5 or greater) = ____________ %
4. Percent Trucks in Design Direction = ____________ %
5. Percent Trucks in Design Lane = ____________ %
6. Initial Truck Factor = ____________
7. Simple Truck Volume Growth Rate = ____________ %
8. Truck Factor Growth Rate = ____________ %

Traffic Analysis for Pavement Design:

9. Design Year AADT
   [(Item 1 - 1) x Item 2 x Item 7] + Item 2 = ____________
10. Average AADT
   (Item 2 + Item 9) / 2 = ____________
11. Design Year Truck Factor
   [(Item 1 - 1) x Item 6 x Item 8] + Item 6 = ____________
12. Average Truck Factor
   (Item 6 + Item 11) / 2 = ____________
13. AADT in One Direction
   Item 10 x Item 4 = ____________
14. Truck AADT in One Direction
   Item 13 x Item 3 = ____________
15. Daily 80 kN (18 kip) ESAL Count
   Item 14 x Item 12 = ____________
16. Total 80 kN (18 kip) ESAL Count
   Item 15 x 365 x Item 1 x Item 5. = ____________

Table A-7. 80-kN (18-kip) ESAL calculation work sheet for the "simple" method with compound traffic growth.

Input Parameters:

1. Design Life = ____________
2. Initial AADT = ____________
3. Percent Heavy Truck (Class 5 or greater) = ____________ %
4. Percent Trucks in Design Direction = ____________ %
5. Percent Trucks in Design Lane = ____________ %
6. Initial Truck Factor = ____________
7. Compound Truck Volume Growth Rate = ____________ %
8. Truck Factor Growth Rate = ____________ %

Traffic Analysis for Pavement Design:

9. Traffic Volume Growth Factor
   $[1 + \text{Item } 7]^{(\text{Item } 1 - 1)}$ = ____________
10. Truck Growth Factor
   $[1 + \text{Item } 8]^{(\text{Item } 1 - 1)}$ = ____________
11. Design Year AADT
   Item 2 x Item 9 = ____________
12. Average AADT
   (Item 2 + Item 11) / 2 = ____________
13. Design Year Truck Factor
   Item 6 x Item 10 = ____________
14. Average Truck Factor
   (Item 6 + Item 13) / 2 = ____________
15. AADT in One Direction
   Item 12 x Item 4 = ____________
16. Truck AADT in One Direction
   Item 15 x Item 3 = ____________
17. Daily 80 kN (18 kip) ESAL Count
   Item 16 x Item 14 = ____________
18. Total 80 kN (18 kip) ESAL Count
   Item 17 x 365 x Item 1 x Item 5 = ____________

Table A-8. 80 kN (18 kip) ESAL calculation work sheet for the "rigorous" method with simple traffic growth.

Input Parameters:

1. FHWA Vehicle Classification = ____________
2. Design Life = ____________
3. Initial AADT = ____________
4. Percent of AADT = ____________ %
5. Percent Vehicles in Design Direction = ____________ %
6. Percent of Vehicles in Design Lane = ____________ %
7. Initial Truck Factor = ____________
8. Simple Truck Volume Growth Rate = ____________ %
9. Truck Factor Growth Rate = ____________ %

Traffic Analysis for Pavement Design:

10. Design Year AADT

    [(Item 2 - 1) x Item 3 x Item 8] + Item 3 = ____________
11. Average AADT

    (Item 3 + Item 10) / 2 = ____________
12. Design Year Truck Factor

    [(Item 2 - 1) x Item 7 x Item 9] + Item 7 = ____________
13. Average Truck Factor

    (Item 7 + Item 12) / 2 = ____________
14. AADT in One Direction

    Item 11 x Item 5 = ____________
15. FHWA Vehicle Classification Volume in One Direction

    Item 14 x Item 4 = ____________
16. Daily 80 kN (18 kip) ESAL Count for FHWA Vehicle Classification

    Item 15 x Item 13 = ____________
17. Total 80 kN (18 kip) ESAL Count for FHWA Vehicle Classification

    Item 16 x 365 x Item 2 x Item 6 = ____________

Table A-9. 80-kN (18-kip) ESAL calculation work sheet for the "rigorous" method with compound traffic growth.

Input Parameters:

1. FHWA Vehicle Classification = ____________
2. Design Life = ____________
3. Initial AADT = ____________
4. Percent of AADT = ____________ %
5. Percent Vehicles in Design Direction = ____________ %
6. Percent of Vehicles in Design Lane = ____________ %
7. Initial Truck Factor = ____________
8. Compound Truck Volume Growth Rate = ____________ %
9. Truck Factor Growth Rate = ____________ %

Traffic Analysis for Pavement Design:

10. Traffic Volume Growth Factor

    $[1 + \text{Item 8}]^{(\text{Item 2} - 1)}$ = ____________
11. Truck Growth Factor

    $[1 + \text{Item 9}]^{(\text{Item 2} - 1)}$ = ____________
12. Design Year AADT

    Item 3 x Item 10 = ____________
13. Average AADT

    (Item 3 + Item 12) / 2 = ____________
14. Design Year Truck Factor

    Item 7 x Item 11 = ____________
15. Average Truck Factor

    (Item 7 + Item 14) / 2 = ____________
16. AADT in One Direction

    Item 13 x Item 5 = ____________
17. FHWA Vehicle Classification Volume in One Direction

    Item 16 x Item 4 = ____________
18. Daily 80 kN (18 kip) ESAL Count for FHWA Vehicle Classification

    Item 17 x Item 15 = ____________
19. Total 80 kN (18 kip) ESAL Count for FHWA Vehicle Classification

    Item 18 x 365 x Item 2 x Item 6 = ____________

3. "Rigorous" ESAL Calculation

Table A-8 should be used as a work sheet to calculate total anticipated 80-kN (18-kip) ESAL count applications for each FHWA vehicle classification for a simple traffic-volume growth rate. Once the work sheet is completed for each class, values in Item 17 for each vehicle classification should be entered in the corresponding area of Table A-10. The sum of values entered in Table A-10 will be the total anticipated ESAL count for design life of the pavement structure. Table A-9, which assumes a compound growth rate, should be used in the same manner as Table A-8 and in conjunction with Table A-10 to calculate total anticipated ESALs.

Table A-10. Total 80-kN (18-kip) ESAL applications for design life of pavement structure.

Vehicle Class	80 kN (18 kip) ESAL Applications
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
Total	

APPENDIX B

SUBGRADE IMPROVEMENT METHODS

APPENDIX B. Subgrade Improvement Methods

The design philosophy for the subgrade area (defined generally as that portion of the embankment or natural ground located within 0.6 m (2 ft) below the surface on which the pavement structure is placed) is 1) to provide a uniform, stable platform on which to place the pavement structure and/or 2) to minimize differential frost heaves. Measures are provided to reduce the amount of water in the subgrade area or to replace, densify, and/or drain such non-uniform subgrade features as high bedrock and wet, unsuitable soils:

1. Methods to improve drainage or to reduce the amount of water in the subgrade area create roadside ditches to a depth of 1.2 m (4 ft), measured from the pavement edge to the ditch flow line. Edge drain outlets are placed a minimum of 300 mm (12 in.) above the ditch flow line. Underdrains and broken rock trenches may be used to lower the water table in cut sections.

2. Numerous methods may be used to improve uniformity as a means to minimize differential frost heaves or increase load-bearing capacity. The most common is to remove unsuitable (organic) or unstable (saturated) materials and replace them with a select granular material that is not frost-susceptible. Subbase material alone or in combination with a geotextile may also replace removed material. Where rock is encountered, it may be fragmented and the fragmented area drained. Transition sections at culverts and in boulder-removal areas are also used to provide uniformity. The following factors should be evaluated when determining replacement of subgrade material with select granular subgrade:

    1. Percent of fine soil in the subgrade (fine sand and silt heave the most),

    2. Percent of boulders in the subgrade,

    3. Variability of the subgrade soil,

    4. Depth of frost penetration.

    The designer should contact the Regional Soils Engineer for recommendations concerning the need to replace subgrade material.

3. Other methods less commonly used are simple manipulation of in-situ material to break up stratified layers into more uniform material. Heavy rolling has been used to densify landfill materials; the rollers are 27 to 45 metric ton (30 to 50 US ton) proof-roller-type compactors. Clay soils have been stabilized by addition of lime.